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Comparing Two Immersive Virtual Environments for Education

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Abstract: The Virtual Cell is a 3D multi-user educational game teaching principles of Cell Biology. The Geology Explorer is also a multi-user educational game, but teaching principles of Physical Geology with a 2.5D interface. These systems were tested over several years, using an identical experimental design. This paper describes these systems, a set of experiments conducted in 2003 using large sample sizes, and the comparative results of these experiments. The general results of this study are that 1) gender does not affect success in games of this type and 2) neither does pre-treatment computer literacy or 3) previous gaming experience, and 4) that 3D versus 2.5D interfaces do not significantly effect the students' perception of the learning experience. Specific comparisons between the Virtual Cell and the Geology Explorer showed that students perceived the Virtual Cell as more difficult, while the Geology Explorer was perceived as more fun.

1. Introduction

Comparing educational software systems is difficult for a number of reasons. There are a large number of variables to consider – differing teaching goals must be accounted for, especially across disciplines, sample sizes are usually small, data is often hard to collect and manage, and studies are normally conducted with different experimental designs. All these factors contribute to the complexity of the comparison, and explain why such studies are rarely completed.

The Geology Explorer (Saini-Eidukat, Schwert & Slator, 2002), and the Virtual Cell (White, McClean, & Slator, 1999), are immersive virtual environments (IVEs) developed at North Dakota State University (NDSU) by the Worldwide Web Instructional Committee (WWWIC). These are both 'Desktop Virtual Reality' systems developed for use in college-freshman-level introductory science classes, and both have been hosted at NDSU since the late-1990s in large enrollment classes. Each is deployed on the Internet and has the capability of multi-user interaction. The common technology is a LambdaMOO (Mud Object Oriented; Curtis 1997), server and database that contains the contextual material (help files and experimental output data), and controls the single and multi-user connectivity and interactivity.

2. Example: The Geology Explorer

The Geology Explorer (Figure 1), is an educational simulation built on the model of the 'field camp' where students are brought into the field by experienced geologists, and assigned tasks that train them to think and act like their mentors. Learners participate in field-oriented expedition planning, sample collection, and 'hands on' scientific problem solving.

To play the game, students are transported to the planet's surface and acquire a standard set of field instruments. Students are issued an 'electronic log book' to record their findings and, most importantly, are assigned a sequence of exploratory goals. These goals are intended to motivate the students to view their surroundings with a critical eye, as a geologist would. Goals are assigned from a principled set, in order to leverage the role-based elements of the game. The students make their field observations, conduct small experiments, take note of the environment, and generally act like geologist as they work towards their goal of, say, locating a kimberlite deposit. A scoring system has been developed, so students can compete with each other and themselves.

More advanced modules implemented in the Geology Explorer include a "geologic mapping" exercise where students build on their outcrop identification skills by 'painting' a map of the underlying structure of a region featuring an intrusive Basaltic dike. Later they use 'strike-and-dip' measurements to determine the 'tilt' of the underlying stratigraphy. These are fairly advanced procedures that enable the students to interpret a geologic setting as a geologist would. The Geology Explorer is available at URL site: http://oit.ndsu.edu.

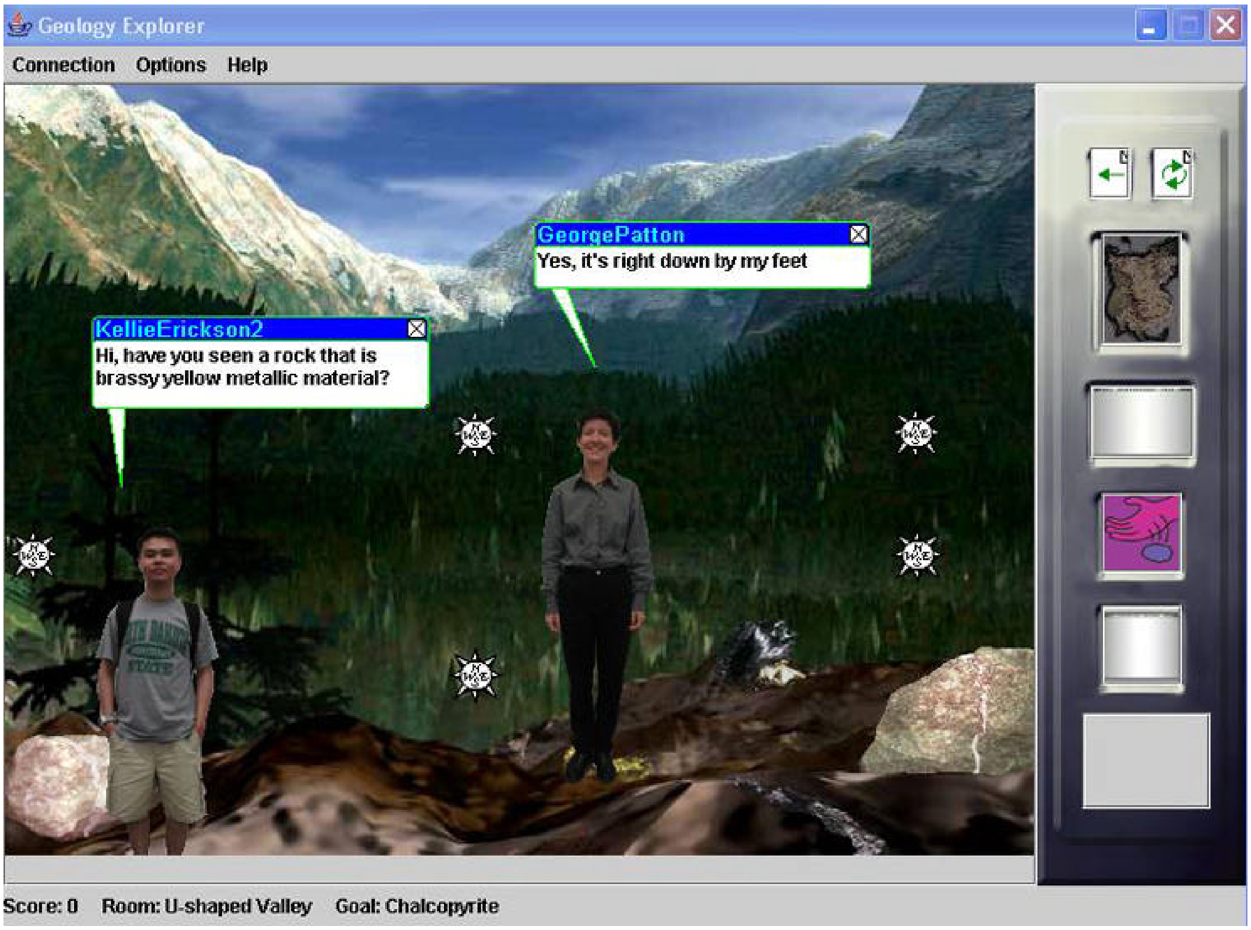

Figure 1: The Geology Explorer interface showing two players working on a goal together.

The Student Body

Physical Geology (GEOL 105) is offered every Fall semester as a lecture-based course in the largest NDSU teaching space, Stevens Auditorium. This is a course that satisfies general education science requirements. Thus, it is routinely attended by students who are majoring in non-science disciplines, from English to Physical Education. Indeed, GEOL 105 is affectionately known as "Rocks for Jocks". However it is also the first in the sequence for Geology majors, and there are usually a dozen or so of these every semester, plus a cadre of Civil and Construction Engineering students who are required to take it for their major.

The Fall 2003Experience

In the Fall of 2003 the class list for GEOL 105 contained 373 names. The students were required to participate in the Geology Explorer study as part of their class work. This participation accounted for approximately 5% of their final grade (about 1/2 of a letter grade, which is the system at NDSU).

3. Example: The Virtual Cell

The NDSU Virtual Cell (Figure 2), is an educational simulation that draws its inspiration from "The Fantastic Voyage" and "Inner Space". Students are introduced to cell biology by enabling them to explore and experiment as though they were themselves at the molecular level. In this environment, experimental goals are in the form of question-based assignments that promote deductive reasoning and problem solving in an authentic visualized context.

Three modules currently exist in the Virtual Cell game. The first module, Organelle Identification, has students performing assays on various organelles to determine if a cell is defective. The next module, Electron Transport Chain (ETC), allows a student to put the complexes in different orders to determine how it affects the overall outcome of the ETC. Finally, the Photosynthesis module gets the student to think about the importance of adding certain molecules at specific times during the Photosynthesis process. The Virtual Cell is available at URL site: http://vcell.ndsu.edu

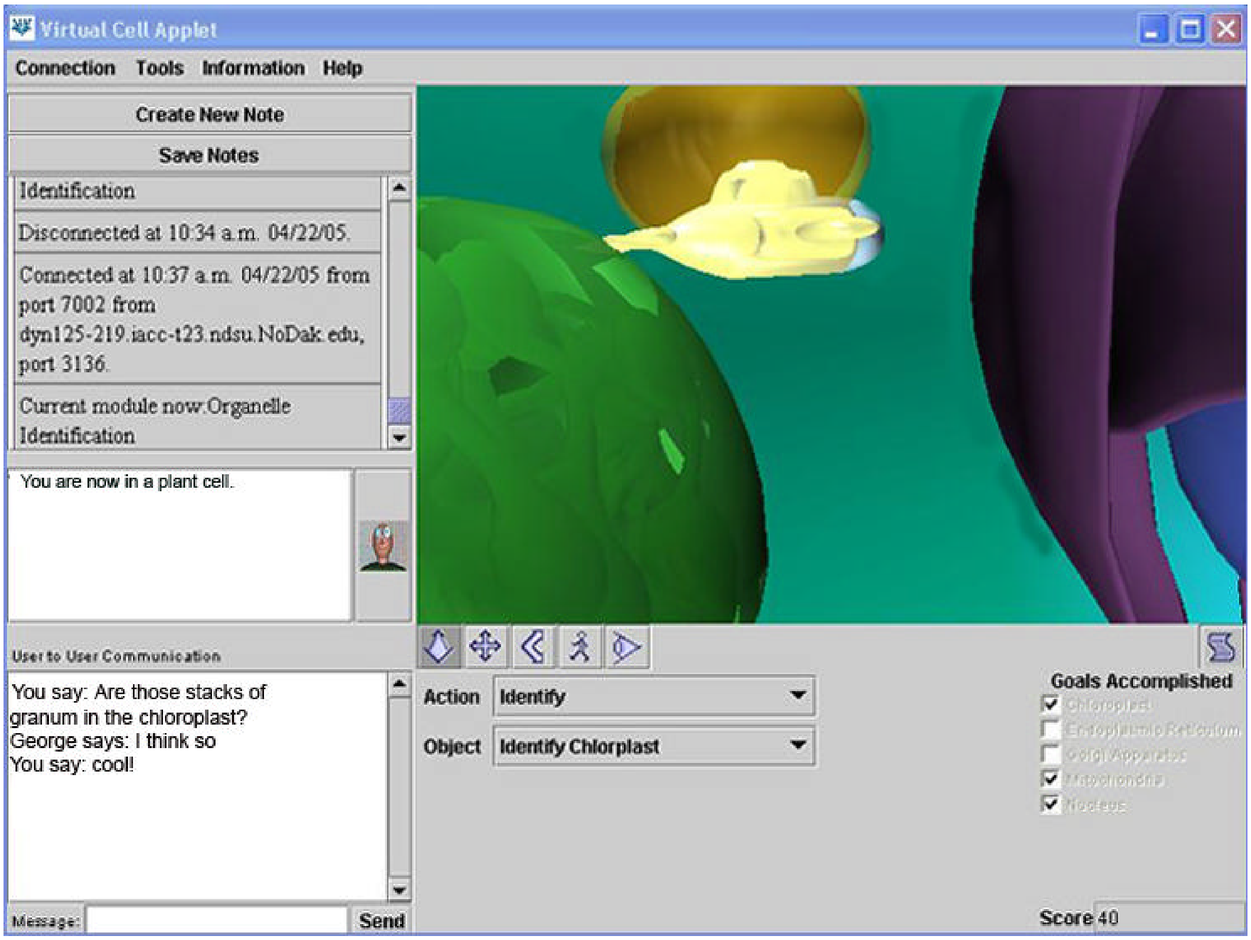

Figure 2: The Virtual Cell interface showing a player (in the form of a submarine).

The Student Body

Introduction to Biology (BIOL 150) is offered every semester, also in Stevens Auditorium. This is a course that is pre-requisite to many of the science majors offered at NDSU: botany, biology, nursing, pre-med, various health-related disciplines, and zoology. These are somewhat motivated students who would be considered, as a group, to be somewhat above average.

The Fall 2003Experience

In the Fall of 2003 the class list for BIOL 150 contained 544 names. The students were required to participate in the Virtual Cell study as part of their class work. This participation also accounted for approximately 5% of their final grade. These students were divided into two sections that were taught by two different instructors.

4. Background: The Experimental Design

The studies described conform to the same experimental design (Figure 3). Biology and Geology student participants received a grade worth five percent weight of their overall class grade. Students completed a pre-treatment scenario-based assessment exercise. They also received a survey to distinguish their computer literacy, gender, and prior lab experience. Students were randomly divided into two groups based on the survey information. The first group played the educational game as their treatment while the second group performed World Wide Web exercises. In the Virtual Cell World, biology students completed Organelle Identification, Cellular Respiration. In Geology Explorer, students were assigned a single authentic mineral identification activity and allowed to identify other minerals while completing the specific activity. The alternative group completed two computer-based World Wide Web exercises that required a similar amount of time with computer-based activities. Afterwards, students completed a post-treatment assessment and an evaluation pertaining to user satisfaction.

Figure 3 illustrates the similarities in the experimental design employed in these studies. Both groups were divided into game and web-based groups (268 and 276 for the Virtual Cell web-based and game play groups, 163 and 210 for the Geology Explorer game play and web-based groups), based on balancing the samples according to computer literacy, gender and previous laboratory experience. This approach was taken to avoid confounding factors, such as one group accidentally being populated with all the computer adept students, or all the females (since there are many published results indicating gender is significant in the arena of computer games). Once the students were divided into balanced groups, based on the computer literacy survey used for both studies, their experiences diverged into web-based exercises or the game-based 'treatments': the Virtual Cell or Planet Oit. The pre- and post-treatment scenario-based assessment was different for each group, in that the scenarios were relevant to the discipline, as were the treatments. At the end, however, all groups were administered essentially the same evaluation survey. These are the data that form the focus of this paper.

Computer Literacy Survey

Both groups received a survey to identify their computer literacy, gender, and prior lab experience. The results of the survey indicate the student's ability to use computer games, work in Microsoft Office programs, and also shows their familiarity with computers and the Internet.

Examples of multiple-choice questions where students answer not at all, moderately, or very:

- How comfortable are you with using computers for playing games?
- How comfortable are you with using computers for word processing?
- How comfortable are you with using computers for spreadsheets/databases?
- How comfortable are you with using computers for participating in on-line discussion groups?

Pre-Treatment Survey

Each student participant completed a pre-treatment scenario-based assessment exercise. These exercises were problem-based questions specific to their discipline. Subjective scenarios were used to assess the effectiveness of the virtual environment. For the Biology participants, the first two scenarios assessed the Organelle Identification Module, and the third scenario applied to the Electron Transport Chain Module. For the Geology participants, a single scenario was used as a pre-treatment and another, slightly different, was used for the post-treatment assessment.

Treatment Activity

As illustrated in Figure 3, the students were assigned to treatment groups at this point. For this paper, we concentrated on the 'game play' groups that participated in the Virtual Cell and the Geology Explorer. The 'web-based' and 'other' groups were assigned to other activities entailing approximately equal time-on-task as the game playgroups. This division was performed for the sake of the scenario-based studies reported elsewhere (McClean et al., 2001).

Post-Treatment Survey

After treatment, each participant completed a post-treatment scenario-based assessment exercise. The post-treatment is similar to the pre-treatment where the same assessments are made on the scenarios in the exercise. The only difference was different scenarios implemented between the pre- and post-treatment.

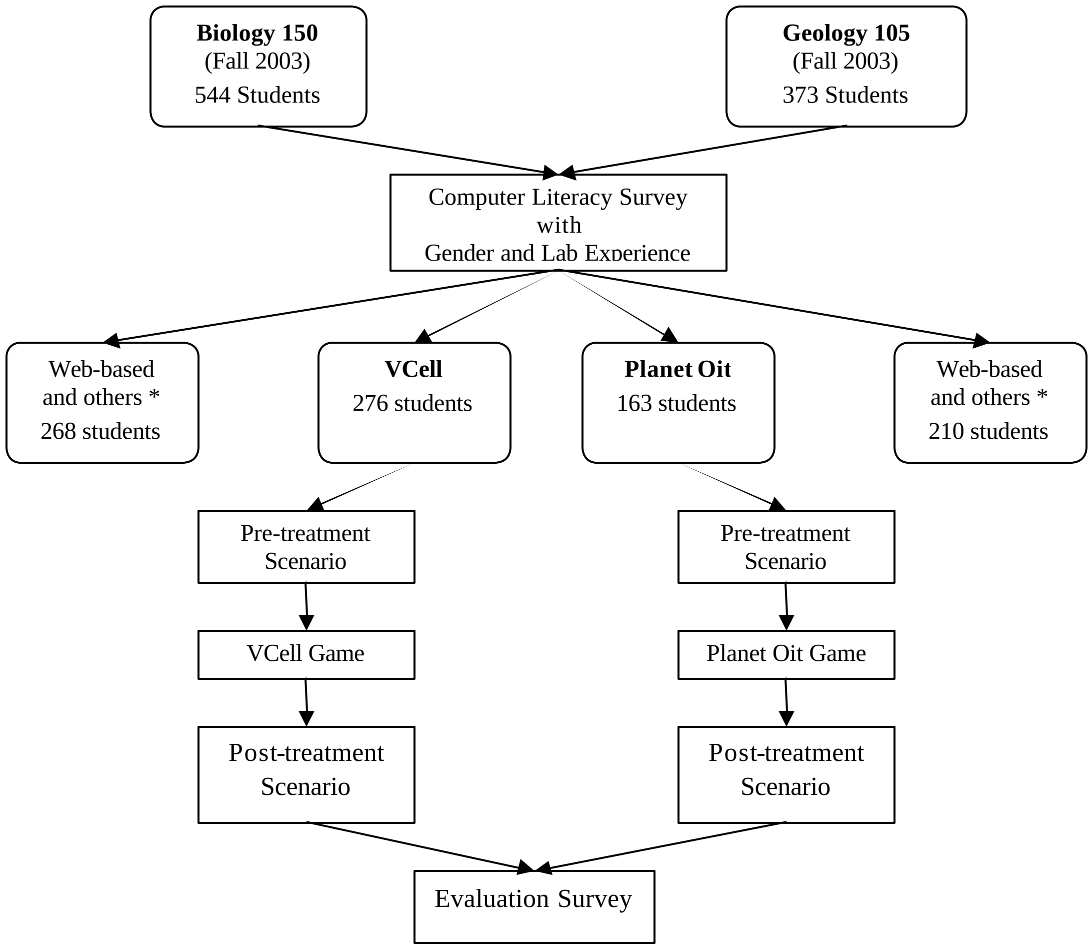

Figure 3: Flowchart for the experimental design of the studies described here.

Game Evaluation Survey

Both groups were essentially administered the same evaluation survey. The survey obtained student feedback about the level of difficulty, complexity, navigation problems, and satisfaction with the game's visual interface. The majority of questions required a response with a rating of one to five. The last two questions required students to approximate the amount of time they spent on the game and to comment on what they liked/disliked about the game and suggestions for improvement.

Examples of questions:

- The game was complex(1)/simple(5) to learn
- I was able to keep track of my progress(1)/unable to keep track of my progress(5)
- There was too little detail in the game(1)/too much detail in the game(5)
- The game was visually entertaining(1)/visually dull(5)

Using the data provided from the experiments, statistical analyses were conducted to compare the two educational games. Since the two games were similar in many aspects, the analyses focused on feature differences between the two games and also features of interest, such as possible correlation between prior game experience and ease of game operations. The Virtual Cell and Geology Explorer are multi-user educational games that combine the fun of computer games with the engagement of virtual environments. The Virtual Cell and Geology Explorer employ software tutors to promote learning and help with game play. Game motivation is similar between the groups since experiment participation was worth 5% of their final grade. Students' computer literacy scores were not found to be significantly different ($p = 0.05$) between the two games.

Difference in features includes the Geology Explorer implementing a 2.5D interface while the Virtual Cell implementing a 3D interface. Another distinction can be made between their navigation systems; Geology Explorer uses a navigation system where students move to the last mouse click position in the scene. Whereas, the Virtual Cell uses a navigation system where students click on 'navigation' buttons, such as fly, and then click and drag the mouse in the direction they want to move. The scoring system also distinguishes the two games, which could affect the motivation level in the game. In Geology Explorer, students must obtain the minimum score, but they are able to obtain extra points in addition to their minimum score. In the Virtual Cell, students obtain points by completing each activity, so if students want to complete the game, they are required to obtain a fixed amount of points. There is also the marked difference between the two science disciplines.

5. Results: Comparing Two Virtual environments for Education

The analyses we conducted took the following form. The test groups consisted of student participants who completed each question in the computer literacy test, pre-treatment scenario, post-treatment scenario, game evaluation survey, and played a portion of the game where their score was at least greater than zero points. After narrowing our data to match these requirements, we had 163 students in the Geology Explorer and 276students in the Virtual Cell.

5.1 *Performance comparison by gender*

The two sample t-test (two-tailed) with unequal sample size was performed to determine if there was a significant difference in game performance between male and female students (Table 1). In the experiment, game points students earned measures game performance. For Geology Explorer, game score is the points earned for completing the specific tasks in addition to points earned for identifying minerals and completing their geologic map. For Virtual Cell, current score is the sum of points students earned for each completed task.

	Geology Explorer			Virtual Cell	
Gender	Sample Size	Game Score	Map Score	Sample Size	Current Score
Male	116	1709.83	31.24	109	314.86
Female	47	1703.55	32.55	167	326.78
p-value		0.97	0.85		0.09

Table 1: Mean Performance Comparisons by Gender (Fall 2003)

The t-test results show no significant differences in performance between male and female students in the Geology Explorer and the Virtual Cell experiments. To ensure a family error rate of no more than 10%, the Bonferroni method (see e.g. Section 3.5 of Kuehl (2000)) was used to determine significant p-values. For instance, in this analysis, a significant p-value would correspond to a value of 0.10/3 = 0.0333 or less. We note that the p-value of the Virtual Cell (0.09) is considerably smaller than the Geology Explorer (0.97) for game score and (0.85) for map score). Due to the several differences listed above, it is difficult to adequately explain this discrepancy based solely on the t-test results. However, we note that the variances between male and female groups of the Virtual Cell are significantly different ($p < 0.0001$), compared with the Geology Explorer ($p = 0.40$ for game score and ($p = 0.78$)for map score).

5.2 *Comparison between 2.5D and 3D interfaces*

The Two sample t-test with unequal sample size was used to determine if there was any significant differences in game satisfaction between a 3D interface implemented in the Virtual Cell and a 2.5D interface implemented in Geology Explorer. In the experiment, assessment of 2.5D and 3D satisfaction was represented by student's answers in the game evaluation survey.

Once again, the Bonferroni method was used to determine significant p-values (e.g. $p < 0.10/7 = 0.0143$ for this set of comparisons). Rows 5 and 6 of Table 2 show there is no significant difference between game satisfaction in 2.5D and 3D environments for the Geology Explorer and the Virtual Cell, and the educational content of the game in both cases was more important than the quality of its characters, setting, graphics, sound, or interface . Instead, students were more concerned about game performance, game difficulty, clear game goals, and their ability to control different tasks (see rows 1, 2, 3, 4, 7 of Table 2).

Evaluation Question	Geology Explorer Means		Virtual Cell Means		P–values
	Sum		Sum		
I was able/unable to keep track of my goals	400	2.45	765	2.77	0.0163
I had too little/sufficient control over my progress	537	3.29	682	2.47	< 0.0001
The game was too difficult/easy	477	2.93	624	2.25	< 0.0001
There was too little/too much detail in the game	565	3.47	823	2.97	0.0005
The game was visually entertaining/dull	519	3.18	940	3.39	0.0947
There was enough/too little visual detail	513	3.15	820	2.96	0.2735
I learned/did not learn something from the game	440	2.70	925	3.34	< 0.0001

Table 2: Comparisons between 2.5D and 3D Interfaces

5.3 *Comparison between perceived student difficulty and perceived student enjoyment*

Again, the two sample t-test (two-tailed) and Bonferroni method with unequal sample size was used to determine if there was any significant differences in the students' perceived difficulty versus their perceived enjoyment during game play (Table 3). In the experiment, assessment of game difficulty and student enjoyment was represented by responses to the game evaluation survey. Students answered the questions by a rating of one to five. In the difficulty question, one signified the student found the game difficult while a five signified the student found the game to be easy. In the enjoyment question, a one represented the student thought the game was fun while a five represented the student did not think the game was fun.

Evaluation Question	Geology Explorer Means		Virtual Cell Means		P-values
	Sum	Mean	Sum	Mean	
The game was difficult/simple to operate	416	2.55	500	1.82	< 0.0001
The game was fun/was not fun	553	3.39	1129	4.08	< 0.0001

Table 3: Perceived student difficulty and student enjoyment.

By closely examining the Geology Explorer and Virtual Cell means it appears that students thought the Geology Explorer game was simpler to operate and more fun than what students thought of the Virtual Cell game. Since the t-tests for both evaluation questions are statistically significant, we might suspect that perceived student difficulty is related to perceived student enjoyment. More specifically, students who had a difficult time during game play did not have as much fun as students who had an easier time during game play.

5.4 *Correlation between overall computer literacy versus self-assessment of learning*

Correlation analysis was performed to investigate if there was any correlation between overall computer literacy and assessment of learning (Table 4). In the experiment, self-assessment of learning was represented by the responses to a game evaluation question, "I learned something/did not learn anything from the game." Responses were defined with one indicating the student learned something from the game and a five indicating the student did not learn something from the game. The objective learning effect was measured by the points earned in the game (game score and map score in the Geology Explorer and current score in the Virtual Cell).

Pearson Correlation Coefficients	Geology Explorer			Virtual Cell	
	Self-assessment of Learning Score	Game Score	Map Score	Self-assessment of Learning Score	Current Score
Overall Computer Literacy Score	0.039	0.031	-0.053	-0.055	0.007

Table 4: Correlations Between Overall Computer Literacy and Assessment of Learning

Table 4 shows that there is no correlation found between computer literacy and the students' self-assessment of learning.

5.5 ***Correlation between previous game experience and complexity, difficulty, speed in the educational games***

Correlation analysis was performed to identify if previous game experience had an effect on how students viewed complexity, difficulty, and speed in the educational games. In the study, game complexity, difficulty, and speed were represented by answers obtained from three questions in the game evaluation survey: "The game was complex/difficult to learn", "The game was simple/difficult to operate", and "The game was too fast/slow." Prior game experience was defined by the student's answer to a computer literacy question, "I am comfortable with playing computer games." If the students answered 'very', it indicated the student had previous game experience while a 'not at all' indicated little or no game experience.

Pearson Correlation Coefficients	The Geology Explorer			The Virtual Cell		
	Game Complexity	Game Difficulty	Game Speed	Game Complexity	Game Difficulty	Game Speed
Previous Game Experience	0.073	0.010	0.019	0.078	0.015	-0.054

Table 5: Correlations Between Previous Game Experience and Game Complexity, Difficulty and Speed

Table 5 shows there are no significant correlations, which indicates previous game experience does not effect how students perceive game complexity, difficulty and speed.

6. Conclusion

The results reported above speak for themselves, but must be viewed in the context of those variables that were beyond control. Yes, these studies have the incomparable advantage of large numbers, but this does not account for all the effects we observe. While the student populations are much the same (freshmen in a science class offered at NDSU in the Fall of 2003), they are also noticeably different (non-science majors in the Geology Explorer group versus science majors in the Virtual Cell group). The effect of this difference is extremely hard to judge.

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